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CRPL

NBS RESEARCH IN RADIO PROPAGATION

a broad program of research in radio propagation insures development of better systems, more accurate standards, and more reliable propagation forecasts for use by government, industry, and science

THE INCREASED utilization of the space available in the radio spectrum by almost every phase of industry, commerce, science, and the armed services has been the determining factor in formulating the program of the Central Radio Propagation Laboratory (CRPL) of the National Bureau of Standards. Technological developments have advanced the science of communications and electronics so that equipments now function at frequencies up to 100,000 megacycles. Accompanying these advances is the growing need for more information about the characteristics of radio energy under diverse conditions. Thus, in order to more effectively serve these interests, the National Bureau of Standards is establishing a new multimillion-dollar radio research laboratory in Boulder, Colorado.

As the Nation's central agency for collecting radio propagation data, CRPL in turn analyzes and disseminates information that aids reliable global aviation, all-weather shipping and harbor control, and worldwide communications. The Laboratory's studies of frequency allocation and interference affect the establishment and operation of AM, FM, and TV broadcast stations. Data on ultra-high-frequency radio propagation and the development of improved microwave methods are important to the Weather Bureau and military aerologists for use in upper-air temperature, humidity, and wind measurements. Accurate measurement methods and standards maintained by CRPL are essential to studies in many branches of engineering and physics. Also, many industrial applications of radio require CRPL standards and measurement techniques.

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Air view of the National Bureau of Standards new research center in Boulder, Colorado. This structure will house the Bureau's Central Radio Propagation Laboratory. The design of the building features a four-story central spine, with one-story wings extending from it on either side. The structure takes advantage of the sloping terrain that rises from a state highway toward the Flatiron mountains to the west. The buildings in the background, also part of the research center, are part of the NBS–AEC Cryogenics Engineering Laboratory. This 200-acre site was donated to the Federal Government by the citizens of Boulder. A plaque commemorating this act will be made a permanent part of the building.

early radio propagation activities

Radio propagation studies were formally begun at the Bureau in 1909 with the measurement of low-frequency radiations. The radio signals at these frequencies traveled comparatively short distances and only along the surface of the earth (so-called ground-wave transmission). The studies were extended to include higher frequencies after the basic demonstrations of ionospheric reflection of radio waves in 1926. In these experiments, the radio waves were directed toward the upper atmosphere (50 to 300 miles above the earth's surface). Here, the layers of ionized gases act very much like mirrors and bend the higher-frequency radio energy back toward the earth. Thus, by using ionospheric reflections, it became possible to transmit radio signals over extremely long distances.

In the subsequent decade NBS increased the scope and amount of its ionospheric measurements and theory, and developed techniques that were incorporated later in military radar and radio. However, full achievement of the value of systematic collection of radio propagation data was not accomplished until the Combined Chiefs of Staff (U. S. Armed Forces) established the "Interservice Radio Propagation Laboratory" (IRPL) at NBS in the spring of 1942.

During World War II, IRPL rendered continuous service to the military establishments. A direction-finder study, begun under the National Defense Research Committee (NDRC), was taken over by the Laboratory. Large quantities of ionospheric and other radio propagation data were accumulated from all over the world. With the development of radar, the need was further increased for propagation information at ultrahigh frequencies (UHF) and at the microwave frequencies (greater than 3,000 Mc). Many groups from the Army, Navy, and Air Force were trained in the use of radio propagation information and techniques. Continuous liaison was maintained with the military concerning their communications operations. Staff members from the British and Canadian Navies and the R. A. F. were assigned to IRPL, and liaison officers were assigned for duty with similar organizations in Australia, New Zealand, Great Britain, and Canada.

Regular ionospheric predictions were issued in a form that later became the monthly publication "Basic Radio Propagation Predictions," CRPL Series D. A

disturbance warning service was also established to forecast ionospheric storms that would interrupt radio communications. An extensive reporting and analysis program was maintained by NBS, the Carnegie Institute of Washington, the Army Signal Corps, and others active in the study of radio propagation. Hundreds of special propagation problems of both technical and strategic value to communications and intercept work were solved. The most usable frequencies for many types of communications to all parts of the world were determined. Accompanying problems involving antenna design, power and receiver requirements, and frequency allocations were also solved. In addition, NBS was employed in the development of VHF and UHF standards, countermeasures work, and the regular standards activities carried over from before the war.

The service performed by IRPL and the other propagation laboratories during the war not only increased the dependability of radio but also showed that still greater improvements in radio equipment and communications could be attained through continued research. This experience showed that propagation information and research were vital to the effective use of radio communication, direction finding, radar, radio navigation, or any devices employing radio waves.

At the end of the war, a survey of future work needed by the Army, Navy, Air Force, Coast Guard, FCC, and non-Government interests led to the conclusion that the whole field of basic propagation research should be centralized. It was realized that if the progress and services rendered during the war were not continued, the Nation would lose much of the benefit derived from the original effort. Moreover, the United States would be at a disadvantage in comparison with other countries, while at the same time military and civilian radio activities would be greatly hampered. In addition, many Federal agencies, under the exigencies of wartime, had developed organizations working not only on applications of propagation to their problems, but also on fundamental research along parallel lines. Centralization of basic propagation research common to all the user agencies seemed, therefore, the best scheme to meet the needs of the country in this field without needless duplication of work.

Although the need for coordination was apparent, the magnitude of the task was too complex to achieve success in one organizational step. Accordingly, on May 1, 1946, the Central Radio Propagation Laboratory was established as one of the technical divisions of the National Bureau of Standards. A Radio Propagation Executive Council, organized to formulate general policy, included representatives of the Army, Navy, Air Force, FCC, CAA, Coast Guard, State Department, and the radio industry. Besides the existing IRPL functions, the new Laboratory assumed the duties of the NBS Radio Section. These included the maintenance and development of radio standards, the operation of radio broadcasting station WWV (which transmits standard radio frequencies, time signals, audio signals, and radio propagation information), the incipient standards work on high frequencies, radio countermeasures, and radiosondes; all of which are related, directly or indirectly, to propagation. Of particular importance was the promotion of standards development in the then-unexplored but rapidly growing fields of ultrahigh and microwave frequencies.

Thus, the program of the new Central Radio Propagation Laboratory was designed to include all aspects of radio propagation research and investigation and many related activities. Experimental programs of worldwide scope were planned. These included measurements of radio field intensity, ionospheric absorption, radio noise, solar and geophysical effects, the structure of the atmosphere and ionosphere, and the influence of the ground and troposphere on radio propagation.

The information obtained from these studies of radio wave propagation is analyzed and disseminated by CRPL to all interested users of radio communications. The material is also employed in preparing predictions of radio-wave propagation conditions 3 months, 2 weeks, or even 6 hours in advance. As part of the

Network of world-wide observatories supplying CRPL with solar activity information. (Numbered flags designate location of each observatory.) 1: NBS and Naval Observatory, Washington, D. C.; 2: Cornell University, New York; 3: McMath-Hulbert Observatory, Michigan; 4: Sacramento Peak, New Mexico; 5: Climax, Colorado; 6: Boulder, Colorado; 7: Mt. Wilson, California; 8: Greenwich, England; 9: Meudon, France; 10: Wendelstein, Germany; 11: Kanzelhohe, Austria; 12: Pic du Midi, Pyrenees; 13: Tokyo, Japan; 14: Mt. Stromlo, Austria; 15: India; 16: Sweden; 17: Italy.

operation of two standard-frequency radio broadcasting stations (WWV and WWVH), CRPL dispenses radio disturbance warnings to users of communications circuits over the North Atlantic and North Pacific areas. Further, the Laboratory has custody of the national primary standards of all electrical quantities used at frequencies between 10 kc and 100 kMc, and performs calibrations in terms of these standards.

The role of CRPL in national defense is both basic and operational. It conducts basic research and development work for use of the armed services and their contractors, and provides much of the operational information and guidance in the field of applied radio propagation. The value of CRPL's program became even more apparent during the latter part of 1950 when its activities were again directed toward the needs of national defense and the requirements of the military.

CRPL prediction services were used for determining operating frequencies for both strategic and tactical operations in all parts of the world. Both long-haul, point-to-point, and intertheater communications utilized the detailed predictions that only the Laboratory could make, and for which the experience of the IRPL was invaluable. The Laboratory assisted in the preparation of tables of frequencies for communications between fleets and naval bases, flight charts for aircraft communications, tables and nomograms for frequency allocations, and detailed short-term predictions for specific areas. Warnings of sudden radio disturbances or ionospheric storms which could interfere with radio communications were sent to the armed services, with instructions as to what action should be taken to maintain communications. Ionosphere recorders were installed at field and advance-base propagation stations to obtain on-the-spot information. Analysis and testing of navigation and direction finding systems were necessary to insure the success of fleet operations, aircraft, missions (both long- and short-distance), and intercept and intelligence work. Propagation data and standards over wide frequency ranges were required for phases of radar such as search, early warning, fire control (ground, air, naval, antiaircraft), blind bombing, navigational radar, beacons, identification, and distance-measuring equipment.

Exterior of NBS radio broadcasting station WWV, Beltsville, Maryland. From this station, standard radio frequencies of 2.5, 5, 10, 15, 20, and 25 Mc are transmitted continuously. Two standard audio frequencies, 600 and 440 cycles, are broadcast as modulation on each radio frequency.

current CRPL activities

Current activities are divided along research lines essentially according to the manner in which radio energy is propagated. Responsibility for pursuing the program is assigned to three laboratories and a service section. The Ionosphere Research Laboratory investigates the physical phenomena affecting the ionosphere and radio propagation in and through the ionosphere (50 to 300 miles above the earth's surface). The Systems Research Laboratory is concerned with the characteristics of radio systems depending on propagation in the troposphere (up to about 10 miles above the surface of the earth). The Measurements Standards Laboratory performs research and develops standards and methods of measurement for all electrical quantities used at radio frequencies. Finally, the CRPL propagation prediction services correlate the widespread observations made by CRPL and other laboratories (both foreign and domestic) and prepare propagation predictions for users of the radio spectrum.

These many activities have uniquely prepared the NBS Central Radio Propagation Laboratory for the role of consultant and adviser to the Federal Government on matters pertaining to international radio communication agreements. Members of CRPL have served on many international commissions and have given their services to many national committees concerned with the allocation of radio communication circuits.

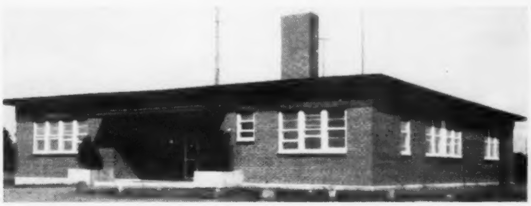
Interior of NBS radio broadcasting station WWV. The banks of six transmitters are carefully monitored and precisely controlled to generate signals with an accuracy of two parts in 100 million.

Ionosphere Research Laboratory

Like most of the major functions in CRPL, the program of the Ionosphere Research Laboratory is based on primary research in the physical laws governing radio propagation. Studies of electromagnetic wave propagation theory are required to ascertain and apply the physical laws that form the framework for practical operating techniques. The studies also provide a basis for extrapolation of existing theories to new situations without costly reproduction of field experiments. Closely related are theoretical investigations of the mechanism of radio frequency emission from the sun,

in particular, solar noise bursts. On the experimental side, a 50-foot array of radiometers is being constructed near Boulder; and two other radio telescopes are used to measure solar emissions in the 160- and 480-Mc frequency regions. The upper atmosphere physics program includes an investigation of the complex motions which this region undergoes as a result of the gravitational tidal forces exerted by the sun and the moon. For instance, experiments using radio reflections from the ionosphere have shown that winds in the upper atmosphere have periodic variations and travel at speeds up to 300 miles per hour.

A thorough knowledge and understanding of the nature and cause of ionization in the upper atmosphere is vitally important to the operation of the CRPL prediction service. Characteristics of the ionospheric layers are determined at many radio sounding stations throughout the world. Some are operated by NBS; others form a network of cooperating observatories that exchange information at regular intervals. NBS-maintained field stations are located at Anchorage and Point Barrow, Alaska; Ft. Belvoir, Va.; Narsarssuak, Greenland; Ramey Air Force Base, P. R.; Ft. Randolph, Canal Zone; Guam; and Maui, Territory of Hawaii.

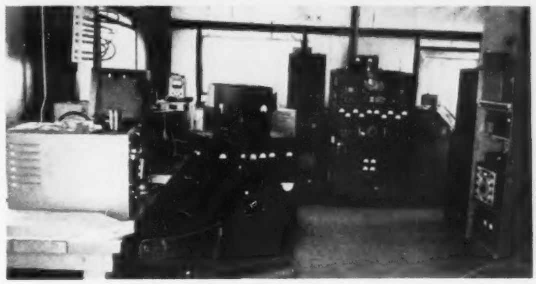


Administration building at the NBS field station at Sterling, Virginia. The building includes office space, sleeping quarters, and extensive laboratory facilities. Several laboratories located on the station grounds conduct research and perform experiments on equipment and methods for studying radio-wave propagation by the troposphere and the ionosphere.

The propagation data received by CRPL from a selected group of such radio sounding stations, together with information from cooperating solar and magnetic observatories, are the basis for NBS forecasts of ionospheric radio propagation disturbances. General forecasts, a few weeks and days in advance, are prepared from the 27-day recurrence tendency of ionospheric disturbances and from application of solar-terrestrial relationships. More specific forecasts are made a few hours in advance from studies of variations in the earth's magnetic field and from trends in ionospheric and radio propagation observations over a broad area. Advance forecasts are furnished directly to representatives of civilian and military government communication agencies, commercial enterprises, technical laboratories, and individuals. Short-term forecasts every 6, 8, or 24 hours are furnished to representatives of key agencies and have wide distribution by broadcast and teletype. Short-term forecasts for communication circuits across the North Atlantic are prepared every 6 hours in the NBS forecasting center at Ft. Belvoir (Va.) and broadcast twice each hour by radio station WWV. Similar forecasts for paths across the North Pacific are prepared in the Anchorage (Alaska) forecasting center and broadcast by radio station WWVH.

In addition to studies of the ionosphere directly related to the transmission of intelligence, CRPL conducts an extensive research program aimed at discovering how the upper atmosphere may be useful even during critical disturbance periods. A multifrequency ionosphere recorder sweeping from 1 to 25 Mc in as

Exterior and interior of NBS field station established near Boulder, Colorado, to study oblique incidence signals transmitted from Sterling, Virginia. The C3 ionosphere recorder (right, background) is one of the basic instruments used widely by science and the military for investigating the outer atmosphere by radar techniques.



little as 15 seconds was developed for routine observations at all field stations. In addition, CRPL pioneered in developing a multifrequency recorder covering the low- and very-low-frequency ranges, from 50 kc to 1.15 Mc. It is hoped that, through study of the fundamental properties and basic laws governing the practical usage of low frequencies, an understanding will be obtained that will permit more accurate prediction of the behavior of transmitted radio energy.

Instruments have recently been completed to measure precisely the velocity of propagation of radio waves over the earth at frequencies between 100 and 200 Mc. Measurements will be made of the effects of atmospheric conditions and the effects of reflection from terrain features on the velocity. The measurements are expected to yield useful information on the ultimate accuracy and reliability of certain types of radio navigation systems.

Large radio telescopes located at NBS field station on Gun Barrel Hill, Colorado. Each device is tuned to receive signals of a different frequency radiated from the sun. The telescopes automatically track the sun as it moves across the sky.

Included in the prediction and forecasting services of CRPL are recommendations of the maximum usable frequencies that may be employed during any transmission period. Studies are being continually conducted over long-distance paths to observe effects such as scattering of radio waves of certain frequencies by the ionosphere or the ground. These effects are additional tools for the study of propagation conditions and improvement of communications. A controlled radio path has been established between Sterling, Va., and Boulder, Colorado (1,500 miles); and as an experiment a circuit was established between Sterling, Va., and Cedar Rapids, Iowa, using the moon to reflect the signal. Still other studies are being performed in the arctic regions to find why and how communication on certain frequencies is affected by the highly active aurora.

CRPL is also developing new and improved antenna systems for propagation investigations. A model antenna range, one of the largest of its kind, is used to investigate antennas in a model ratio of 60 to 1.

The ever-increasing use of radio waves for both civilian and military purposes and the corresponding demands for useful frequencies make the problem of frequency allocation more and more acute. The present trend is to utilize higher and higher frequencies, and thereby extend into the microwave region as far as practicable. In this region, perhaps the chief factor limiting the prediction of propagation conditions is atmospheric absorption. In order to obtain data on this phenomenon, large cavity resonators (100 centimeters in diameter) have been constructed. They have a cavity Q (measure of efficiency) of over one million. With this apparatus, it is possible to study molecular structure through microwave spectra, ionic absorption, and the absorption of atmospheric constituents under various meteorological conditions.

Systems Research Laboratory

All of the systems research activities of CRPL were transferred to Boulder, Colorado, in 1951. Here the rolling plains extending hundreds of miles eastward from the mountain regions are utilized in many phases of radio propagation research. The mountains, too, are put to use: several transmitters are located on Cheyenne Mountain, near Colorado Springs, which affords an almost perpendicular drop of more than 2,000 feet to the floor of the plains. The program of this laboratory is divided between frequency utilization research and investigations of tropospheric propagation phenomena.

Frequency utilization research is concerned with obtaining information to assist in the allocating, regulating, and advisory activities of such agencies as the Federal Communications Commission, International Radio Consultative Committee, the Armed Forces, and various other governmental and private organizations employing radio methods of communication, navigation, and control. Experiments have been conducted in which mobile recording units have traveled over areas serviced in common by several TV and FM stations to determine the amount of interference offered by each station. Other mobile stations have been placed on top of Pike's Peak to determine the effects of antenna heights on radio wave propagation. The accumulation of such noise data on terrestrial and extraterrestrial noise from all parts of the world is expected to assist in the prediction of noise levels in relation to geographical location, season, time of day, frequency, and phase of the sunspot cycle. A suitable receiver-recorder has now been developed with such necessary special features as narrow bandwidth, good noise figure, high stability, and multi-channel recording features.

The several types of modulation available for the transmission of intelligence are also studied by CRPL because of their effect on both the allocation and utilization of frequencies. This program includes a determination of information-bearing capabilities, minimum bandwidth requirements, and minimum satisfactory signal-to-noise and signal-to-interference ratios for various systems, as well as effects of choice of frequencies and fading of signals.

Mobile research unit used by NBS to measure the field strength of radio signals. Mobile units such as these have been sent to Pike's Peak to determine the range of transmitted signals from installations in the general area. Others have cruised in service areas common to several transmitters to determine the amount of interference offered by each station. The antenna (on top of trailer) can be raised to a height of 30 feet by remote control while the unit is in motion.

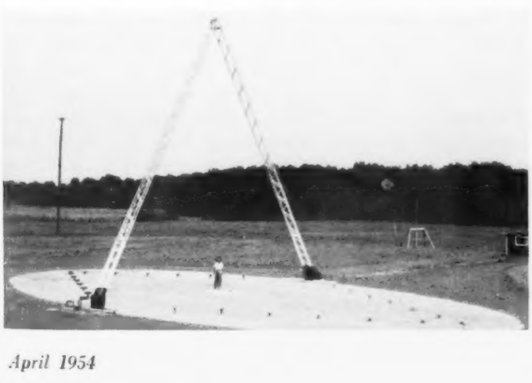
Transmitting antennas at the summit site of NBS field station on Cheyenne Mountain, Colorado, employed in the CRPL tropospheric propagation research program. The metal tower supports two antenna arrays for transmitting signals at frequencies of 100 and 198.2 Mc. The semi-pyramidal horn antenna at the base of the tower radiates 1.6 megawatts at a frequency of 1,046 Mc. This summit site is one of two similar installations on Cheyenne Mountain: the summit is 8,800 feet above sea level; the second site is 1,100 feet lower, but does not include the 1,046-Mc transmitter.

Studies of the effect of irregular and inhomogeneous terrain were originated by CRPL to provide basic information and theories for application to system studies, and, in general, to promote further understanding of the physical concept of electromagnetic wave propagation in the presence of such terrain. Experimental data from other sources, such as the Armed Forces and the FCC, are integrated into the CRPL program for study and analysis. Mobile field-strength measurements are made over various types of terrain at frequencies up to 500 Mc. The experiments are conducted with single or double transmitters employing antennas up to 30 feet in length. Conventional house-trailers have been modified to carry the electronic transmitting and recording equipment relatively shock-free over rough terrain. A series of experiments dealing with the refraction and tropospheric reflection of radio waves over mountain obstacles has led to a new concept concerning the installation in mountainous regions of TV and FM broadcasting stations.

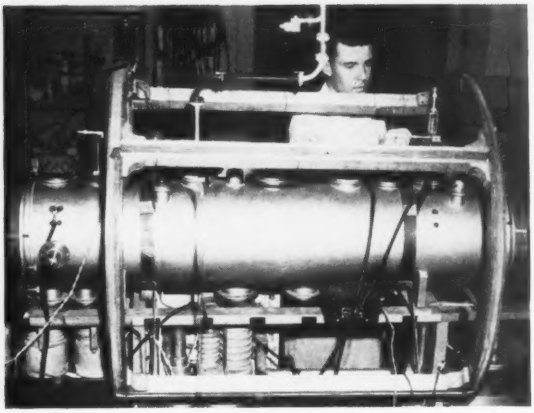
Besides the sun and terrain, the troposphere has also been found to have a profound influence on radio propagation, particularly at frequencies above 50 Mc. This influence is most striking at distances beyond the line of "radio sight," where the cause of abnormally high observed field strength levels and of seasonal and diurnal (daily) variations are not well understood. Experiments have shown the presence of reliable signals more than 500 miles from the transmitter, whereas previous theories predict a maximum range of only somewhat greater than the radio horizon at the frequencies employed.

Several transmitters are installed on Cheyenne Mountain and on Pike's Peak as part of a research program designed to obtain field-strength data under all types of air-to-air, air-to-ground, and ground-to-ground radio transmitting conditions. By making measurements at frequencies between 100 and 1,600 Mc, data are obtained which permit a correlation with the relatively large amount of existing FM and TV propagation data. This information has disclosed certain radio-wave characteristics that existing theories have not predicted. These data also serve as a basis for establishment of more comprehensive and exact theories governing propagation of radio energy in the troposphere.

In order to study the meteorological conditions associated with the observed results from the Cheyenne Mountain tropospheric propagation research program, a 500-foot tower has been installed along the transmission path near Haswell, Colorado. Special meteorological instruments and microwave refractometers developed by the Bureau are employed on the tower to study the variations in refractive index of the lower portion of the atmosphere. These variations have been found to have an important influence on the strength and fading characteristics of VHF and UHF radio signals received at great distances. During recent years, several Government agencies have organized this type of information into a form suitable for the efficient allocation of radio frequencies in the radio spectrum ranging around 50 Mc. The Radio Technical Committee for Aeronautics, for instance, has requested CRPL to supply information that will eventually lead to the allocation of frequencies for air-ground communications and navigational facilities.



NBS model antenna range. This range is believed to be the largest of its kind designed to measure antenna radiation patterns in the vertical plane. The inverted-V structure supports a self-contained target transmitter at the vertex and is designed to move in a 180-degree arc. The antenna to be tested is placed at the center of the oval-shaped ground plane. The model techniques that are used permit an investigation of antenna characteristics in the 1- to 25-Mc region while actually operating at frequencies between 60 and 1,500 Mc.



NBS atomic beam clock. A beam of cesium atoms is made to move down the cylinder from the left to a detector at the right. A microwave signal excites the atoms and makes them spin or precess like a top at a frequency of approximately 9,200 Mc. The microwave signals are derived from a "clock" or signal generator which can then be set exactly in tune with the spinning cesium atoms. Experiments with the atomic beam clock have indicated accuracies of better than one part in 10 billion.

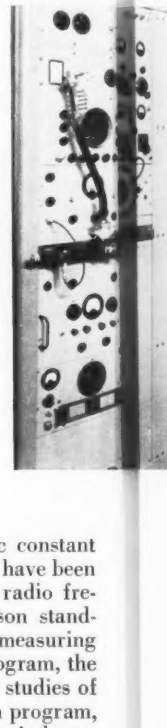
A program is in operation to supply basic radio propagation data for the frequency range of 30 to 6,000 Mc in a form adaptable for use in operational analysis of different communications systems. The Department of Defense, through one of its agencies vitally interested in radio propagation information for the VHF and UHF portion of the spectrum, has assisted CRPL in obtaining a large amount of radio transmission loss data over almost the entire United States. The analysis and interpretation of these data must take into consideration the seasonal and diurnal variations occurring in the different regions of the world. The information will also be related to such factors as antenna heights, terrain effects, meteorological and climatological conditions, and antenna directivity effects.

Measurement Standards Laboratory

The Central Radio Propagation laboratory is responsible for the maintenance and development of electrical standards and standards of measurement in the frequency range between 30 kc and 100,000 Mc. The NBS standard of frequency is composed of a series of quartz crystal oscillators, each of which vibrates at an extremely constant rate of 100,000 cycles per second. The reference vibrations are electrically multiplied and divided to produce a whole series of standard frequency signals ranging from a few cycles up to 100,000 megacycles. This range makes it possible to conduct precise research and development programs in radio frequency standards. These standards are incorporated into the measurement of quantities such as dielectric constant and power factor, impedance, power, field strength, attenuation, voltage, magnetic permeability, and current. In addition to the "laboratory" standards, CRPL broadcasts standard carrier frequencies (2.5, 5, 10, 15, 20, and 25 Mc) from WWV and three from station WWVH (5, 10, and 15 Mc) that are utilized by organizations depending on precise frequency measurement or control.

The need for standards of electrical quantities applicable to the constantly expanding field of electronics had been recognized for some time, but the establishment of suitable standards has been complicated by rapid developments in the field and the continuous extension of the useful frequency range. Even low (audio) frequency standards have not yet reached the perfection generally desired, and standards at all frequencies are continuously being improved. CRPL maintains a continuing program aimed at developing basic and better transfer standards of measurement, instruments, instrumentation techniques, methods of measurement, and analysis of the electrical quantities.

Microwave adjustable frequency standard with which secondary frequency standards are calibrated for Government agencies, defense activities, science, and industry. The pair of dolly-mounted racks (right) contain the electronic components of the Model II ammonia clock.

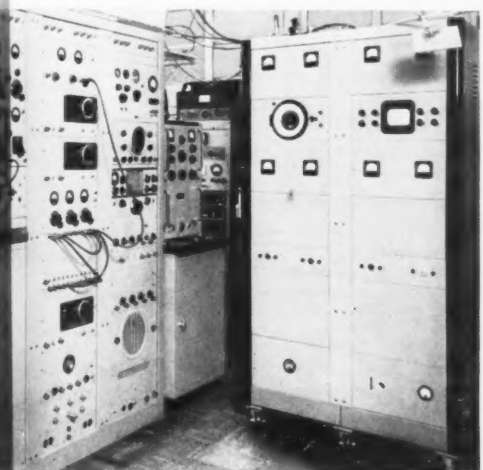


Standard methods of measuring dielectric constant and power factor of solids, liquids, and gases have been established by CRPL over a wide range of radio frequencies. Many instruments and comparison standards have been and are being developed for measuring specimens used in the NBS high-polymer program, the Bureau of Mines oil recovery program, CAA studies of antenna housings, the ASTM standardization program, and for other similar applications by private industry and educational institutions. The expanded development of microwave equipment during World War II has been responsible for added emphasis on the study of dielectric and magnetic properties of materials at the microwave frequencies (300 to 100,000 Mc). A program for the improvement and automation of dielectric measurements has led to the development of refractometers for observing the refractive index of the atmosphere and has contributed to the study of the propaga-

tion of microwaves. Related studies have included investigations of transmission line characteristics, gas measurement, high-Q circuits (reentrant cavities), and the calibration of capacitors, inductors, and special radio components.

In the frequency range between 30 Mc and 300 Mc, standards are being developed for a variety of impedances, including single components, lumped constant and distributed constant networks, and linear and nonlinear, balanced and unbalanced, unilateral and bilateral, active and passive devices. Impedance standards of all magnitudes currently used are being developed. In the 300- to 30,000-Mc range, studies are being made on a waveguide-discontinuity type of absolute standard of impedance and reliable sliding loads for use as secondary standards.

Standard techniques are available for measuring power between 10 kc and 300 Mc, and within the power range between a microwatt and a megawatt depending



on frequency and waveform. Present measuring equipment is capable of handling mostly c-w (continuous wave) power. The equipment will eventually handle pulsed power, c-w modulated and pulse modulated, dissipated or monitored by measuring devices, under matched conditions for optimum efficiency, or when fed into any conceivable impedance. Throughout the frequency range, investigations are in progress on absolute and independent methods of power measurements using devices such as bolometers, thermistors, and calorimeters for cross-checking absolute accuracy. A new microcalorimeter has been developed for low power levels, and work is continuing on the development of a high-power water calorimeter.

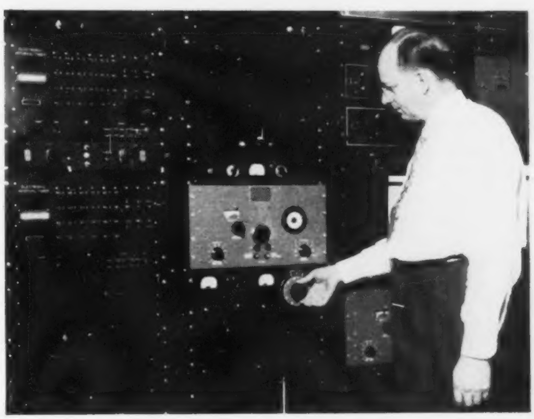
CRPL also maintains programs directed toward the further development of attenuators of various types, notably the waveguide-below-cutoff attenuators for practically the entire frequency range. Reliable primary standards of r-f voltage have been developed for use over a wide range of voltage and frequency; investigations are continuing for the improvement of these standards and the development of new, stable secondary standards. Work is also progressing toward the development of r-f current standards. In cooperation with the FCC and other regulatory agencies, CRPL maintains national reference standards of radio field strength for the benefit of broadcast stations and users of dielecric heating, diathermy, and other interference-producing electrical apparatus.

At the present time, no working primary frequency standards are absolutely free of drift, aging, or instantaneous changes. However, variations have been reduced by a factor of 1,000 within the past 30 years; and a constancy of better than 1 part in 1 billion over a 24-hour period is now available. Nevertheless, requirements in defense, research, and communication still exceed the performance of the best primary oscillators operating under precisely controlled conditions of temperature, vibration, and voltage. Experiments are currently being performed on new types of standards operating at higher frequencies and lower temperatures and on synthetically produced quartz crystals.

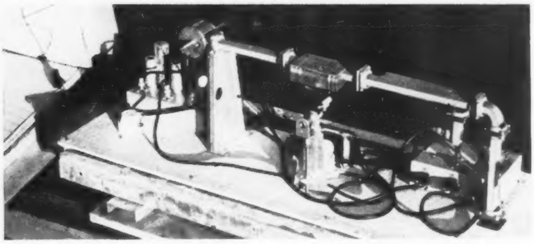
The lack of authentic comparative information on the characteristics of powdered iron and other magnetic materials was responsible for a research program aimed at the development of instruments and methods to measure accurately permeability and loss factor. The resulting instrument is known as an r-f permeameter and serves as a secondary standard. It is now possible to establish specifications for powdered iron based on the accurate results of NBS instruments and standards.

Standard frequency broadcasts were begun by the

NBS primary frequency standard. Temperature-controlled quartz crystals are made to resonate at a frequency of 100 kc. Several of the oscillators are offset from 100 kc by a small number of cycles to permit comparison measurements by dual electronic counters. A variable oscillator is also employed in the comparison measurements.



National Bureau of Standards in 1923 on announced schedules. The usefulness of the broadcasts has been continuously extended, and the service has been improved in accuracy, reliability, and availability in the United States and throughout nearly all the rest of the world. Accurate time signals, time intervals, audio frequencies, radio frequencies, and time announcements in voice and code are now continuously available on six frequencies of WWV (Beltsville, Md.) and on three frequencies of WWVH (Maui, Hawaii). They are relied on by many commercial, scientific, and governmental agencies, as well as the Armed Forces. In addition to the normal maintenance activities associated with the stations, a continuing improvement program is in progress, typified, for instance, by the installation of single-sideband transmitters at WWV to reduce the width of the frequency spectrum now used. Another example is demonstrated by an activity located on Gun Barrel Hill near Boulder, Colorado. Here, CRPL has completed the installation of a laboratory to monitor continuously radio carrier and modulation frequencies and field strength from radio stations WWV and WWVH. The results of this work should prove to be useful in predicting frequency errors to be expected in the carrier and sidebands for different communication paths, time, and carrier frequencies.



Microwave components of NBS microwave refractometer used by CRPL to measure the refractive index of the lower atmosphere. In normal use these components are suspended from a 500-foot tower.

The rapid development during World War II of microwave equipment has led to its application in radar, navigational aids, communication systems, relay systems, and many defense weapons such as guided missiles. In addition to the standards developed for this region of the spectrum, research is being conducted on the utilization of microwaves for atomic frequency and time standards, spectroscopy of gases, and precision interferometry.

The limitations of the present standard of time, the mean solar day, have instigated a search for new methods to determine time and frequency. The original NBS atomic clock utilized the absorption characteristics of ammonia to provide a control element in a servo loop containing a precision oscillator. The success of this initial experiment has led to the further development of atomic clocks utilizing cesium atoms. The latest NBS cesium beam clock now under development is expected to attain an accuracy of 1 part in 10 billion.

The microwave absorption characteristics at microwave frequencies of most gases are being utilized in spectroscopic analysis in much the same manner as infrared and ultraviolet techniques are employed. A current project involves the compilation and dissemination of new and revised information on microwave spectrum lines for use as reference standards and for research purposes.

Optical interferometers have proven invaluable for the precise measurement of short distances and of wavelengths of optical radiations. For microwave frequencies, work is progressing toward the development of a precision interferometer which will measure longer distances (1 to 50 meters) and wavelengths of microwave radiations with great absolute accuracy. The instrument will also make possible a highly accurate measurement of the velocity of light.

Regular Propagation Prediction Services

The radio frequency predictions now issued by CRPL are essentially in the form developed for the armed services during World War II. However, much progress has been made in reducing many of the errors. Included among the errors and common to all systems of predictions are those caused by the lack of accuracy in available methods of predicting solar activity, by insufficient worldwide distribution of ionosphere observations, and by day-to-day variations of ionosphere characteristics around the monthly median values. One serious source of error, that of presentation, use, and interpretation of data, is being overcome by the development of a true map representation of basic radio propagation predictions, both for the entire world and for the Arctic region. It is contemplated that the final form of presentation will consist of 12 maps, one for each even hour of GCT, for a given month, and for each of the characteristics for which predictions are desired.

In order to prepare predictions of the best sky-wave operating frequencies for communication paths all over the world, CRPL collects and analyzes ionospheric data from 76 stations having worldwide geographical distribution. The results of the analyses are compiled and distributed to scientists and scientific organizations in the United States and in many foreign countries. CRPL series F, *Ionospheric Data*, is a 90-page monthly document distributed to the cooperating observatories, military and civilian governmental agencies, industry, and scientific organizations. The series includes, in addition to ionospheric and radio propagation data, tables of solar flares, coronal data, and sunspot numbers, radio propagation quality figures, and geomagnetic data.

CRPL series D, *Basic Radio Propagation Predictions*, is issued monthly as an aid in determining the best sky-wave frequencies over any path at any time of the

day for average conditions for the month of prediction. Each issue of this series predicts the maximum usable frequencies 3 months in advance of their expected occurrence. Included are charts of extraordinary-wave critical frequency for the F2 layer, of maximum usable frequencies for a transmission distance of 4,000 km, of percentage of time for transmission by sporadic-E in excess of 15 Mc for a distance of 2,000 km, and other information concerning the sporadic-E and regular-E layers. Methods for using the charts included in CRPL series D are given in NBS Circular 465, *Instructions for the use of Basic Radio Propagation Predictions.*[1]

Twice a month, CRPL issues the Ja series to those who wish later information concerning maximum usable frequencies. Series Ja carries revision factors for the advance radio propagation predictions made in the series D publication. In addition CRPL issues semiweekly the Series J reports, Advance Radio Propagation Forecasts for North Atlantic Paths, to those interested in the quality of reception over these communication circuits. The forecasts include an estimate of propagation quality for the first 7 days after the issuance of the information and an estimate of the disturbed periods within the next 25 days. A similar series, Series Jp, supplies information for users of communication paths across the North Pacific. Still shorter term forecasts are given to NBS radio stations WWV and WWVH for worldwide transmission. And CRPL is prepared to issue reports every hour or oftener by telephone to governmental users requiring this special type of information.

Ionospheric physics, of which the CRPL prediction services represent one of the practical outcomes, has the whole earth and the outer atmosphere as its laboratory; the research "team" includes scientists from many countries who make observations at remote locations. As an agency of the Federal Government, CRPL maintains close ties with its counterparts in other countries, as well as universities, research institutions, and communication companies in the United States and abroad. This type of cooperative study of universal problems of the upper atmosphere and radio propagation will reach a peak of activity in 1957–58 when at least 28 countries plan intensive joint investigations in many fields of geophysics. This period of widespread observational programs coordinated in space or time is called the International Geophysical Year, or IGY.

Through CRPL, the National Bureau of Standards will participate in the IGY by employing its facilities maintained at half a dozen remote outposts. Moreover, the experience and training of its staff will be utilized for observing the outer atmospheric phenomena. The program will include overhead and oblique ionospheric soundings, radar observations of aurora, and some types of ionospheric wind measurements. Special "World Days," selected by an international coordinating agency, will be the occasion for intensive observations of all ionospheric phenomena, as well as solar activity, cosmic rays, and phenomena observable with the aid of rockets. The results of this tremendous program are expected to yield more exact knowledge of many natural phenomena which affect everyday activities in science, industry, and commerce.

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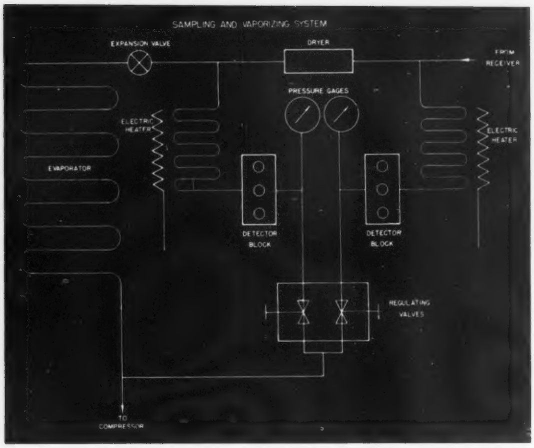
[1] *Available from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., for 30 cents. The Series D publication is available from the same source at 10 cents per issue or on a subscription basis of $1.00 per year (foreign $1.25).*

moisture determination in a circulating refrigerant

A SIMPLE, rapid method for determining the water content of a circulating refrigerant of the fluorocarbon group has been developed by A. W. Diniak, E. E. Hughes, and M. Fujii of the Bureau. Based on the change in electrical resistance of an electrolytic film as it absorbs water vapor, the method is an application of the electrical conductivity method [1] for determining water vapor in gases, developed and used for many years by E. R. Weaver of NBS. The method is highly sensitive, gives accurate results, and does not require the removal of a sample from the circulation cycle. Determinations can be made repeatedly without difficulty, making it possible not only to determine the water content of the refrigerant but also to follow and determine continuously its instantaneous water content before and after passage through a drier.

In commercial refrigeration systems the presence of water in the refrigerant constitutes a serious problem because freezing of the expansion valve and corrosion are always possibilities. Until now there has been no completely satisfactory procedure for determining the moisture content of a circulating refrigerant. Although several good methods for determining the moisture content of refrigerants in static containers are available, none of these is readily adaptable to a circulating refrigerant, chiefly because they require the removal of large samples, which would upset the steady state of the cycle. Such methods are also time consuming and require much experience with the method involved. In contrast, the NBS method is very quick, simple, and convenient. Once a sampling and a return point have been placed in the system, the measuring apparatus can be quickly connected and a determination made in 15 or 20 minutes.

The principle of the method has been used at the Bureau for some time, chiefly to measure small amounts of water vapor in gases. A thin film of hygroscopic material—usually a mixture of sulfuric and phosphoric



Dual system used to determine the moisture content of a circulating refrigerant before and after passage through the drier of a refrigerating system. The method is based on the change in electrical resistance of a hygroscopic film as it absorbs water vapor. Upon leaving the main stream of liquid refrigerant on either side of the drier, the refrigerant passes, by way of a capillary tube, to a heating coil, where it is completely vaporized. The resulting vapor then flows to the detector block, a pressure-tight enclosure containing the moisture-detecting hygroscopic film, where the moisture determination is made. From the detector block the vapor passes through a regulator valve, which limits the flow through the sampling circuit so that very little refrigerant bypasses the evaporator in the main refrigeration circuit.

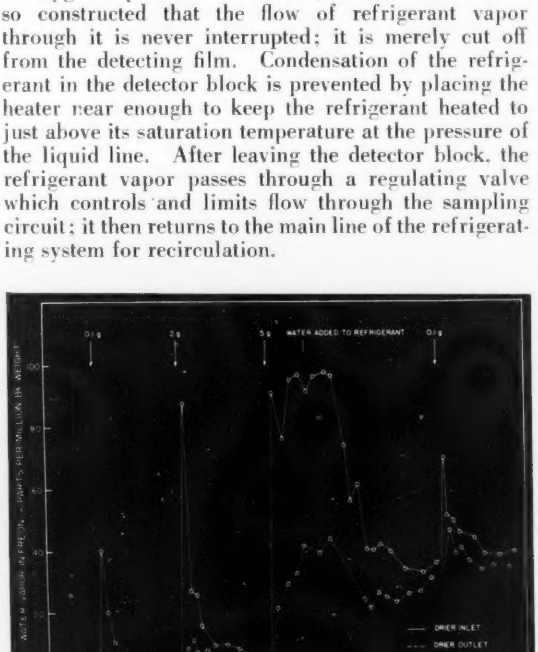
acids—is spread over the surface of a solid insulator between metallic electrodes in a pressure-tight enclosure. The electrolyte tends to reach equilibrium with the water vapor in the surrounding gas and to form a solution whose electrical conductance is a measure of the concentration of water vapor in the gas. This conductance is indicated by a simple electronic circuit and a microammeter.

A gas of known moisture content is used to calibrate the film after each reading. By adjusting the pressure of the comparison gas until the same conductivity reading is obtained for both the known and unknown gas, the two gases can be made to have the same water concentration. The unknown water content can then be calculated from the two pressures and the known water content of the comparison gas at atmospheric pressure.

Usually the comparison gas has been saturated at a high pressure (about 1,000 pounds per square inch) and room temperature in a specially designed saturator and then permitted to expand for use. For very dry systems a secondary comparison gas is employed. This is simply a quantity of fairly dry air whose moisture content has been previously determined by comparison with the saturated air.

Because of the pressure relationships involved and because a liquid would wash away part of the gyroscopic film, the electrical conductivity method can only be used to make moisture determinations of samples in the gaseous state. Thus, in the equipment constructed at NBS, a very small amount of circulating refrigerant is "detoured" from the system, vaporized by heating, passed through the pressure chamber containing the hygroscopic film, and returned to the suction line for recirculation.

To prevent fractionation which would take place if only a part of the liquid sample were vaporized, it is necessary to withdraw the sample through a capillary tube so that the entire sample may be continuously vaporized. The capillary tube, dipping into the main stream of liquid refrigerant, carries a portion of the liquid to an electrical resistance heater which vaporizes the refrigerant. To insure complete vaporization, the tubing containing the liquid refrigerant is wound loosely around the heater in the form of a helix and is thermally insulated from the ambient air. The vaporized refrigerant is then led to the detector block—a specially built, pressure-tight enclosure containing the moisture detecting element. By manipulating three control values in the detector block, either refrigerant vapor or the comparison gas can be caused to flow past the hygroscopic film. However, the detector block is so constructed that the flow of refrigerant vapor through it is never interrupted; it is merely cut off from the detecting film. Condensation of the refrigerant in the detector block is prevented by placing the heater near enough to keep the refrigerant heated to just above its saturation temperature at the pressure of the liquid line. After leaving the detector block, the refrigerant vapor passes through a regulating valve which controls and limits flow through the sampling circuit; it then returns to the main line of the refrigerating system for recirculation.



Drying curves for a typical refrigeration system studied by means of the Bureau's electrical conductivity method for moisture determination. The rapid response of the electrical conductivity method is evident in the sharpness of the peaks in the curve representing moisture content on the inlet side of the drier (solid line). The irregularities in the descending slopes of the curves are due chiefly to local moisture variations throughout the circulating refrigerant. They become quite pronounced after a large amount of water is added.

To establish the validity of the electrical method for moisture determinations in a refrigerant, NBS compared results obtained by this method with the results of gravimetric determinations by the phosphorus pentoxide absorption method. Both types of determinations were made on the same or similar samples of refrigerant at the same, or very nearly the same, time. No important discrepancy was found between the results obtained by the two methods.

[1] Moisture determination by electrolytic film, *NBS Technical News Bulletin* **32**, *13 (February 1948)*.
For further technical details on the application of the electrical conductivity method to circulating refrigerants, see The determination of water in freon-12 circulating in a refrigerating system, *by Albert W. Diniak, Ernest E. Hughes, and Minoru Fugii, Refrigerting Engineering* **62**, No. 2, 56 (February 1954).

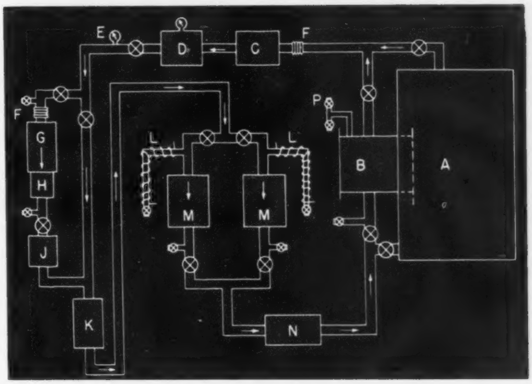
inert atmosphere chamber

A VERSATILE inert atmosphere chamber with an associated purifying system has been constructed that is proving very useful in the Bureau's program of research in electrodeposition. The chamber, which was designed by Abner Brenner and J. M. Sherfey, of the NBS electrodeposition laboratory, permits all the common chemical manipulations such as filtration, distillation, transfer, and weighing to be carried out without contamination of reactants or products with oxygen, water vapor, or carbon dioxide.

As a result of the current widespread interest in a variety of atmosphere-sensitive chemicals, such as hydrides, borohydrides, and metal-organic compounds, there has been a growing need for a device that will permit the chemical manipulation of these materials without resort to elaborate and time-consuming sealed systems often applicable to only one operation. Experience with the NBS inert atmosphere chamber over the past 2 years indicates that it should meet the requirements of most groups that are working with atmosphere-sensitive chemicals on a laboratory scale.

The entire apparatus consists of two principal parts: the air-free chamber, or "dry box," and the purification train. The whole is a closed system, that is, the inert gas passes continuously from the box through the purifying system and back to the box. An antechamber, with an extension for use with longer pieces of apparatus, permits the introduction of apparatus without contamination of the inert atmosphere within the box. Manipulations are performed through four aluminum ports to which are cemented shoulder-length rubber gloves. When not in use, the glove ports can be closed off with metal caps so that gradual diffusion through the rubber of the gloves is prevented. An inverted cylindrical Pyrex jar (12 inches O. D. and 24 inches high) sealed in place over a hole in the top of the box permits the use of tall apparatus such as reflux condenser.

A pump, enclosed in a gas-tight cylinder, circulates the inert gas in sequence through an apparatus for the removal of oxygen (in parallel with a bypass), a heat exchanger to remove heat of compression, two activated alumina dryers in parallel for removal of water vapor, the dry box and its antechamber, and a trap for the removal of acidic gases which might harm the pump or other parts of the system. The gas then returns to the



Schematic diagram of the inert atmosphere chamber and associated purification train. A: dry box; B: antechamber; C: acid trap; D: pump motor assembly; E: pressure gage, 0–5 lb/in.[2]; F: bellows; G: oxygen scrubber; H: heat exchanger; J: flowmeter (1–10 cfm); K: heat exchanger; L: preheaters; M: driers; N: flowmeter (3–30 cfm); P: outlet to vacuum pump.

pump to complete the cycle. The acid trap, containing coarsely granular soda lime, also eliminates carbon dioxide from the atmosphere of the box. Oxygen is removed from the system by passing the gas over copper at 550° C in a specially designed apparatus. Continuous regeneration of the copper is achieved by periodically adding hydrogen to the atmosphere of the dry box.

The box proper is essentially a welded aluminum frame, 34 inches high, 72 inches wide, and 24 inches deep, with plate-glass front, back, and left end. The vertical edges are aluminum angle, and the top and bottom are one-fourth-inch aluminum sheet. One end of the box is of plate glass while the other, to which the antechamber is attached, is of one-fourth-inch aluminum.

The antechamber and its extension are aluminum cylinders having 15-inch inner diameters and walls one-fourth inch thick. The antechamber has a length of 20 inches, which may be increased to 44 inches by attaching the extension with hinged bolts. The inner and outer doors of the antechamber and the door of the antechamber extension close by means of screw-clamp

devices which seal the doors against neoprene O-ring gaskets recessed into grooves in the rims of the openings.

Because the dry box would be ruptured by small changes in pressure above or below atmospheric, it is equipped with a combination oil manometer and pressure-relief device which prevents pressure differences greater than 0.5 pound per square inch. A small closed-end mercury manometer has also been installed to indicate the degree of evacuation of the antechamber. Both of these manometers are sealed in by means of packing glands screwed into aluminum couplings which are welded in place. The interior of the box is provided with electrical outlets and valved hose connections through which water, pressure, and vacuum lines can be brought in.

A flow of about 20 cubic feet of gas per minute through the system has been found adequate and does not require excessively large equipment. A gage pressure of about 3 pounds per square inch is necessary to maintain this flow if argon is used as an atmosphere. About half this pressure is required if helium is being circulated.

The dry box proper is filled with the inert gas by the aid of a very large balloon such as is used in meteorological work. The balloon is placed within the box and is inflated with air through one of the valved hose connections until it essentially fills the chamber. The inert gas is passed into the space outside of the balloon through one of the other hose connections, thus deflating the balloon. Simultaneously the antechamber and pump-motor container are evacuated and filled with the inert gas. After the rest of the system has been flushed, the purification train can be started.

When apparatus is to be put into the box, the outer door of the antechamber is opened, and the apparatus, supported in a specially constructed wire basket, is placed in the antechamber. The outer door is then closed, and the antechamber is evacuated. The inert gas is let into the antechamber until atmospheric pressure is obtained. After which the inner door can be opened and the apparatus can be transferred to the box, working through the gloves. Volatile materials to be taken into the box are kept in a bomb if the evacuation method is used. Otherwise the antechamber is flushed by passing a quantity of the inert gas through it from a supply cylinder. After a suitable period this gas flow can be stopped, and a portion of the flow from the purification train can be directed through the antechamber, effecting a final clean-up before the inner door of the antechamber is opened.

Within a period of 8 hours or less, the system can be filled with inert gas, and the enclosed atmosphere can be virtually freed of oxygen and water vapor. Spilled droplets of liquid sodium-potassium eutectic retain a bright surface after several hours exposure to this atmosphere. While a quantitative estimation of the water vapor in the box has not been made, the oxygen content has been found to be less than 0.1 percent, and the indications are that it is much lower. The extreme dryness of the box is indicated by the fact that no fumes can be seen when a bottle of titanium tetrachloride is opened inside the box.

For further technical details, see An inert atmosphere chamber for laboratory chemical operations, *by Joseph M. Sherfey, Ind. Eng. Chem.* **46, 435** *(1954).*

SCREW-THREAD *PITCH* MEASUREMENT

A TECHNIQUE recently developed by C. E. Haven, of the NBS engineering meteorology laboratory, permits rapid measurement of the pitch, or lead, of internal screw threads without sacrifice of the high accuracy required in this work. The method can be used to determine taper of ring gages at the same time as lead and is adaptable to measurements in very small ring gages, which have hitherto presented a considerable problem. For straight-thread ring gages, the technique has the added advantage that straightness of the bore can be determined simultaneously with lead, thus providing a quick assessment of the amount of wear at the ends of the gage.

In connection with the program of the American Petroleum Institute for standardization of the threaded connections on oil field equipment, the Bureau calibrates master thread gages used by the petroleum industry for calibration of working standards. This is done through the use of thread-measuring instruments whose calibration is ultimately based on the national standard of length maintained by the Bureau. Because the standardized API threaded joints over such an extensive range of sizes—$\frac{1}{8}$ to 20 inches in diameter and up to 6 inches of threaded length—the measurement of some elements of the threads is beyond the range of commercially available measuring equipment, and the NBS and the manufacturers of API gages have had to design special equipment for this purpose. Until now, NBS equipment for determination of lead has required the use of two series of equal combinations of gage blocks for measurement of the intervals, and the procedure involved has been rather time consuming.

The Bureau's more rapid method for measuring lead makes use of a taper-testing machine constructed by Pratt and Whitney Division of Niles-Bement-Pond Company. This device consists primarily of an adjustable sine plate on which the gage to be tested is mounted, and a carriage which travels on accurately machined ways to move a ball-point probe in and out of the mounted gage. When the angle between the sine plate and a normal to the plane of the ways is equal to one-half the taper angle of the gage under test, the pitch line at the bottom of the gage (provided the taper of the gage is straight) will be parallel to the ways. As the carriage moves along the ways, the small ball on the end of the probe contacts the flanks of the threads in the ring gage. If the taper of the gage is true, the ball will remain at the same elevation above the ways

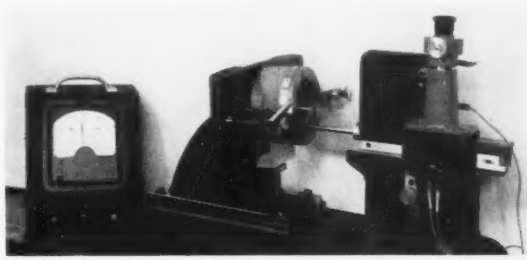
as the probe moves from thread to thread. Variations in the elevation of the probe, caused by errors in taper, are read on an electrically actuated meter.

The Bureau has extended this procedure to permit use of the same settings of the probe to determine lead as well as taper. The NBS method for lead determination involves measurement of the movement of the carriage through the use of a glass scale graduated in increments of 0.050 inch over a range of 4 inches. The glass scale moves with the carriage, and the position of the scale is observed with a microscope having four reticle graduations, each equivalent to 0.01 inch on the scale. A scale graduation is brought into apparent coincidence with the nearest reticle graduation by rotating a plane parallel plate of optical glass in the optical path of the microscope.[1] This parallel plate constitutes a kind of "optical micrometer": that is, the shaft on which it rotates carries a graduated drum having 200 divisions for each 0.01 inch of apparent motion of a scale graduation. This gives a least reading of 0.00005 inch, and permits estimation of fifths of divisions. The scale is accurate to ±0.00002 inch in 1 inch and ±0.00004 inch in 4 inches.

For accurate measurement of lead, the motion of the carriage must be substantially free from friction. This is accomplished by having the carriage roll on 1/4-inch steel balls located in suitable guides. The bottom surfaces of these guides are two parallel **V**-grooves, approximately 3 1/4 inches apart, running the entire length of the base on which the carriage travels. The corresponding upper surfaces of the two guides (running along the underside of the carriage) are formed on one side by a single **V**-groove and on the other side by a flat surface. By viewing with an autocollimating telescope, a mirror mounted on the carriage, it is possible to determine deviation from linear motion of the carriage quite accurately and to make such adjustments of the ways as are necessary to obtain practically straight-line motion of the carriage.

The modified instrument has proved highly satisfactory at NBS for rapid, accurate measurement of the lead of both straight-thread and tapered ring gages. Special probes have been used for measurement of very small thread ring gages. The instrument has also been used to measure the lead of thread plug gages up to 3 inches in diameter. In general, the repeatability of the readings has been found to be as good as the precision with which the scale can be read, that is, between 0.00001 and 0.00002 inch.

[1] *A measuring device manufactured by Hilger and Watts Ltd. (London) is used.*



Equipment used by NBS for simultaneous measurement of pitch and taper of internal screw threads on standard ring gages.

Refractometer Addendum

In the September 1953 issue of the NBS TECHNICAL NEWS BULLETIN, an improved type of refractometer was described. Although the BULLETIN in printing summary articles does not attempt to provide a full bibliography, the following references to earlier refractometers which use Vee-prism assemblies of known refractive indices and sample prisms which did not require polished surfaces indicate prior work in the field:

Industrial Physics Conference of Institute of Physics (England), 1937 Catalogue of the Exhibition, *p. 22.*

J. V. Hughes, A new precision refractometer, *J. Sci. Instr.* **18**, *No. 12, 234 (December 1941).*

J. G. Holmes, A direct reading refractometer, *J. Sci. Instr.* **22**, *219 (November 1945).*

Hilger-Chance refractometer, *J. Sci. Instr.* **28**, *290 (September 1951).*

The improved features of the Grauer refractometer appear to be greater accuracy than the direct reading instrument described by Holmes, and the elimination of the graduated circle. Through the use of a number of prism assemblies, each covering a range of refractive indices limited to about 0.02, a simple filar micrometer eyepiece could be substituted for the accurately graduated circle in the Hilger-Chance instrument described by Hughes.

Publications of the National Bureau of Standards

Periodicals

Journal of Research of the National Bureau of Standards, volume **52**, number 3, March 1954 (RP2479 to RP2486, incl.). Annual subscription $5.50.

Technical News Bulletin, volume **38**, number 3, March 1954, 10 cents. Annual subscription $1.00.

CRPL-D114. Basic Radio Propagation Predictions for June 1954. Three months in advance. Issued March 1954. 10 cents. Annual subscription $1.00.

Research Papers

Reprints from Journal of Research, volume **52**, *number 3, March 1954. Single copies of Research Papers are not available for sale. The Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., will reprint 100 or more copies, and request for the purchase price should be mailed promptly to that office.*

RP2479. Precise measurements with Bingham viscometers and

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Cannon Master viscometers. J. F. Swindells, R. C. Hardy, and R. L. Cottington.

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RP2481. Continuous measurement of atmospheric ozone by an automatic photoelectric method. Ralph Stair, Thomas C. Bagg, and Russell G. Johnson.

RP2482. Applications of dimensional analysis to spray-nozzle performance data. Montgomery R. Shafer and Harry L. Bovey.

RP2483. Silver-uranium system. R. W. Buzzard, D. P. Fickle, and J. J. Park.

RP2484. Nonnegative trigonometric polynomials and certain rational characteristic functions. Eugene Lukacs and Otto Szasz.

RP2485. Flame emission spectrum of water vapor in the 1.9-micron region. W. S. Benedict, Arnold M. Bass, and Earle K. Plyler.

APPLIED MATHEMATICS SERIES

AMS33. Statistical theory of extreme values and some practical applications. 40 cents.

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Anelasticity of quartz. Richard K. Cook and Robert G. Breckenridge. Phys. Rev. (57 East 55th Street, New York 22, N. Y.) **92,** No. 6, 1419 (December 1953).

Electrical indicating instruments used in early Edison central stations. Herbert B. Brooks. J. Franklin Institute (Benjamin Franklin Parkway at 20th Street, Philadelphia, Pa.) **256,** No. 5, 401 (November 1953).

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The convergence of numerical iteration. H. A. Antosiewicz and J. M. Hammersley. Am. Math. Monthly (University of Buffalo, Buffalo 14, N. Y.) **60,** No. 9, 604 (November 1953).

Direct-indicating recording instruments. S. R. Gilford. Elec. Mfg. (1250 Sixth Avenue, New York 20, N. Y.) **52,** No. 5, 114 (November 1953).

The non-Maxwellian distribution in a shock front and the anomaly of the chromospheric temperature. Hari K. Sen. Phys. Rev. (57 East 55th Street, New York 22, N. Y.) **92,** No. 4, 861 (November 1953).

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On the determination of critical micelle concentrations by a bubble pressure method. Lawrence M. Kushner and Willard D. Hubbard. J. Phys. Chem. (1155 16th Street NW., Washington 6, D. C.) **57,** 898 (1953).

A time-proportional electronic thermostat. J. A. Ransom. Control Engineering (330 West 42d Street, New York 30, N. Y.) **1,** No. 1, 85 (January 1954).

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